Characterization of Multilayer Reflective Coatings for Extreme Ultraviolet Lithography

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INTRODUCTION

The synchrotron-based reflectometer at beamline 6.3.2 is an important metrology tool within the current Extreme Ultraviolet Lithography (EUVL) program. The EUVL program is a joint activity of three National Laboratories and a consortium of leading semiconductor manufacturers. Its goal is the development of a technology for routine production of sub-100 nm feature sizes for microelectronic circuits. Multilayer-coated normal-incidence optical surfaces reflecting in the Extreme Ultraviolet (EUV) spectral range near 13 nm are the basis for this emerging technology. All optical components of existing and currently manufactured prototype EUV lithographic steppers need to be characterized for their at-wavelength reflectance during their development and manufacturing process. Multilayer coating uniformity and gradient, accurate wavelength matching and high peak reflectances are the main parameters to be optimized. The mechanical and optical properties of beamline 6.3.2 proved to be well suited for the needs of the current EUVL program. In particular this beamline is highly precise in its wavelength calibration and the determination of absolute EUV reflectivity. Beamline 6.3.2 as well as reference multilayer coatings proved to be stable over a period of more than two years within 0.2 % for reflectivity and 0.002 nm for wavelength.

MULTILAYER DEVELOPMENT

Molybdenum/Silicon (Mo/Si) multilayer coatings with 40 periods, a peak reflectance near 67 %, a centroid position near 13 nm and a bandwidth of about 0.6 nm (Fig. 1) are the current standard for EUV reflective coatings fabricated at the Lawrence Livermore National Laboratory (LLNL)[1]. These coatings are routinely deposited with alternating 2.8 nm thick layers of Mo and 4.1 nm thick layers of Si (Fig. 2). Magnetron sputter film deposition is performed either on Si wafers or polished glass substrates. In order to achieve the above mentioned reflectivity, the high spatial frequency roughness (HSFR) needs to be in the order of 0.1 nm as measured with an atomic force microscope (AFM). An alternative multilayer material combination is Molybdenum/Beryllium (Mo/Be). For this multilayer system a reflectivity of 70% has been demonstrated at a slightly lower wavelength near 11 nm (Fig.1). At this wavelength the spectral match with the laser-plasma EUV source currently under development at Sandia National Laboratories (SNL) would improve the optical throughput of the overall system by a factor of 5. In general there is still a potential for further improvement of Mo/Si as well as Mo/Be multilayers. In particular the stability of multilayers under atmospheric as well as under EUV exposure at realistic EUVL vacuum conditions is currently under investigation. These activities focus on deeper understanding of the top layer interactions under different environmental conditions. Preliminary observations indicate no change in the resonant wavelength, but a loss of reflectivity on the order of a few percent depending on the experimental conditions.

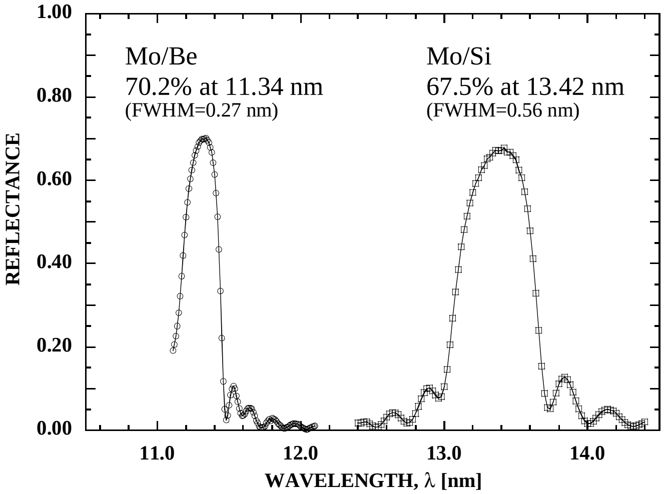

Figure 1: Mo/Be and Mo/Si multilayer reflectance curves.

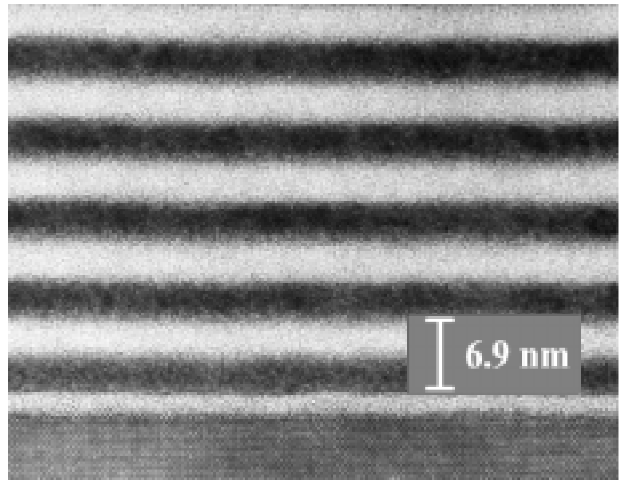

Figure 2: TEM cross section of a Mo/Si multilayer.

COATING OF EUVL OPTICS

Coatings for the 10x Microstepper

Two EUV lithography systems at SNL were recently upgraded with new projection optics. These optics replaced cameras coated earlier [2]. Each new camera consists of two multilayer coated spherical mirrors in a Schwarzschild configuration with greatly improved optical performance. First, better figure and finish of the mirror substrates reduced the wavefront error and the flare of the final optics. Second, the precisely graded multilayer coatings (Fig.3 a, b) increased the wavefront error only by a small amount, well within the error budget. Together with improvements on EUV masks and EUV photoresist, high quality prints of 80 nm 'elbows' were achieved (Fig.4) [3]. Multilayer deposition on the 10x Microstepper projection optics was performed at LLNL. Mirror substrates were spun under a shadow mask during the deposition in order to precisely grade the multilayer thickness along the radius of the mirrors. In an iterative approach several surrogates were coated at LLNL and characterized at beamline 6.3.2. The results were then used for improvements of the mask shape for the next coating run. The goal was to achieve a gradient such that the peak wavelength is matched on all locations of the mirrors for the illumination angles in the Schwarzschild arrangement. Wavelength mismatch would result in throughput losses as well as phase errors, which would lead to decreased image quality.

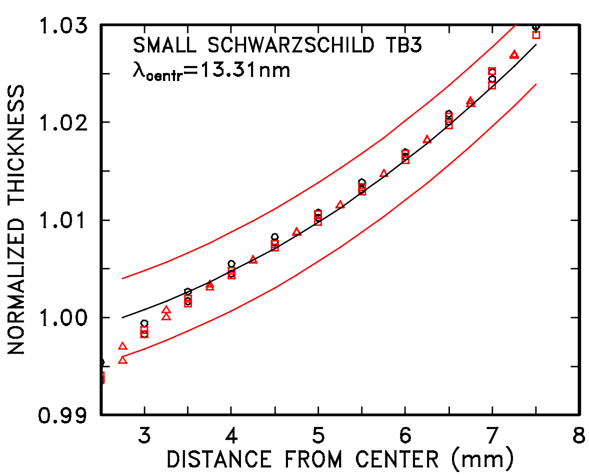

Figure 3a: Grading of the Mo/Si coating on the small 10x mirror.

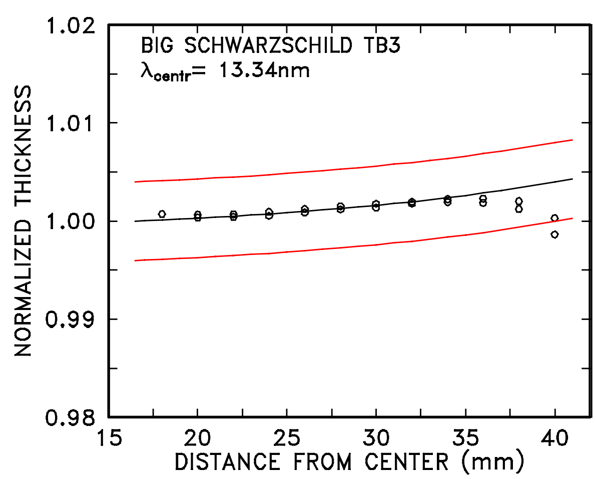

Figure 3b: Grading of the Mo/Si coating on the big 10x mirror.

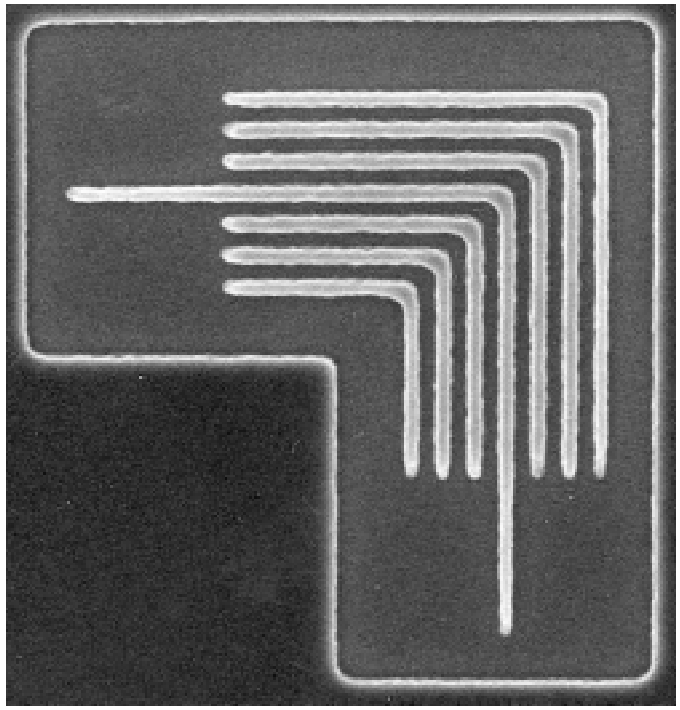

Figure 4: 80 nm 'elbows' printed with a multilayer-coated Schwarzschild camera with numerical aperture 0.088 [3].

Coatings for the Engineering Test Stand

Mirror M3 for the Engineering Test Stand (ETS) projection optics was coated recently. The ETS represents an early prototype EUVL stepper, which will allow printing 100-nm features. Four projection mirrors and four condenser mirrors will be used in the ETS. Along one diameter of projection mirror M3 a uniform coating is needed on its convex spherical surface (Fig. 5a). Along the perpendicular diameter a slight linear grading is necessary in order to compensate for the slightly different angles of illumination (Fig. 5b). The atomic level control of coating uniformity and gradient was possible because of the accurate and precise features of beamline 6.3.2. Long-term high accuracy is needed for wavelength matching all ETS mirrors, while even higher precision is necessary for the determination of the gradient/uniformity of the multilayer coatings.

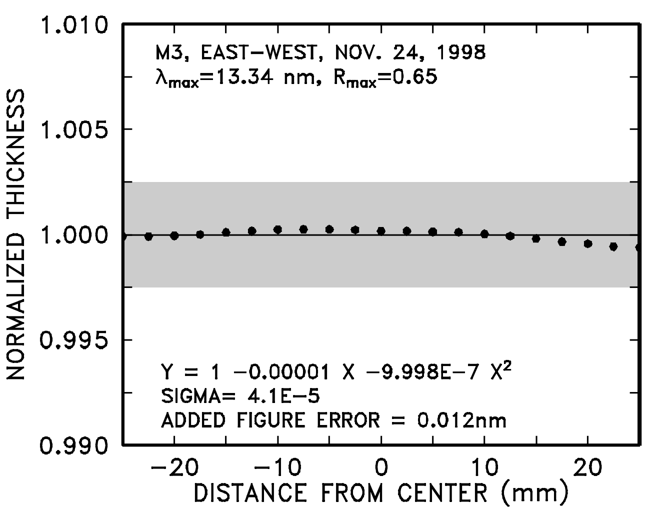

Figure 5a: Normalized multilayer d-spacing variation for the M3 mirror along the uniform diameter.

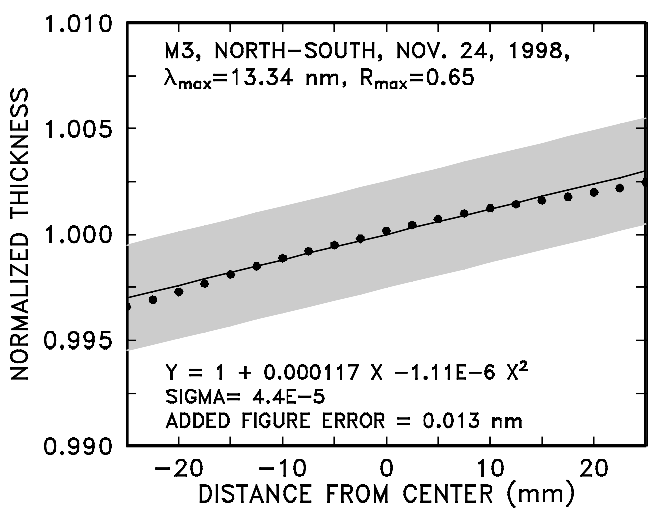

Figure 5b: Normalized multilayer d-spacing variation for the M3 mirror along the graded diameter.

EUVL MASK DEVELOPMENT

Another important task within the EUVL program is the development of multilayer reflective masks for lithographic printing. Low defect density multilayer-coated mask blanks are produced at LLNL for subsequent patterning at the semiconductor companies. The ultra-low defect density deposition of multilayer films on silicon wafers is the critical first step in the manufacturing process of EUVL masks. Mask blanks as well as patterned masks are routinely characterized at beamline 6.3.2 in order to assure wavelength matching, spatial uniformity and sufficient EUV reflectivity throughout the entire mask before and after patterning. Mask patterning requires chemical and thermal treatment, which may influence the multilayer performance dramatically. Absorber covered areas ideally should not reflect at all in the EUV spectral range, while open areas should maintain their full reflectivity.

OTHER EUVL RELATED ACTIVITIES

Other activities, which involve the use of the reflectometer at Beamline 6.3.2 include the development of multilayer stress reduction strategies and substrate recovery techniques.

CONCLUSION

Beamline 6.3.2 is an important tool for the development of Extreme Ultraviolet Lithography. It provides the necessary accuracy for wavelength matching the multilayer coatings in EUV optical systems with several resonantly reflecting surfaces. Furthermore, it provides the necessary precision in order to measure the uniformity or the gradient of multilayer coatings. Finally, it is instrumental in the further development of multilayers by enabling reliable absolute reflectivity measurements. Its precision was determined to be 0.2% for absolute reflectivity and 0.002 nm for wavelength over a long period of time. Multilayer d-spacing uniformity control in the order of 1 part in 1000 allows us to minimize wavefront distortion in EUV optical systems, permitting image patterns such as in Fig. 4 to be obtained.

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